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ANALYTICAL METHOD FOR THE ESTIMATED CALCULATION OF THE REQUIRED AMOUNT OF PROPELLANT CHARGE FOR THE REUSABLE TRAINING-PRACTICE MORTAR ROUND FOR SMALL DISTANCE FIRING

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Abstract: *The paper presents an analytical method for determining the estimated amount of propellant charge for the reusable training-practice mortar round intended for short distance firing, as a part of simulator for mortar crews. For verification of the analytical method an experimental research was conducted where the 82mm training-practice mortar round was fired at a distance of 100 meters. The experimental research and the verification of the statistical hypothesis confirm that the formula can be used to practically determine the required amount of propellant charge.*

Keywords: mortar, training-practice mortar mine

1. Introduction

A tendency aimed towards the modernization of the Bulgarian Armed forces has been seen during the recent decades. The modernization of the armed forces however requires not only new equipment but also the implementation of modern means and methods for training military personnel and in military education institutions.
Part of these tools are the practical simulators. The most common disadvantage found in most practical simulators is the fact that they cannot simulate the full range of the crew's combat functions. In most cases they lack: the practical implementation of activities related to the preparation of ammunition at the fire position (installation of the fuze; setting the fuze function impact or delayed detonation etc.) and activities related to the loading and unloading of the mortar whether a misfire occurs. In addition, training equipment and simulators do not give an accurate notion for the psychological impact that affects the personnel during the use of real ammunition at the firing position and the additional stress accumulated during the firing.
One type of artillery system that is currently in service in the majority of armies are mortars.
In order for a high quality and effective practical, mortar training to be achieved, the development and implementation of a practical simulator is required. The created simulator must not only lower financial expenses but also guarantee a high level of immersion in real combat activities conducted on the firing position during live firing.
Based on the analysis conducted on developed practical simulators for the training of mortar crews in different countries the following basic requirements for the designed simulator can be identified:
- the construction of the simulator must include the basic components that are

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required for live firing: mortar, training-practice mortar round, fuze and ignition cartridge;
- to enable the simulator to most accurately mimic the activities performed by the mortar crew during real combat operations.
- the training-practice mine must resemble, as much as possible, it's combat counterpart in terms of appearance, weight and dimensions. The abovementioned criteria are required in order for the round to provide better practical training and to create a true picture of the round's operation;
- the construction of the training-practice mortar round must have simple technological design that incorporates already manufactured elements from its combat counterpart;
- the training-imitational fuze must be able to mark the area where the round has made impact with the ground. The fuze must be unable to cause fire, but at the same time, must still be capable of clearly indicating the area where the round has made impact;
- the training-practice fuze must fiction reliably and have a simple design and reliable action;
- the construction of the training-practice fuze must incorporate a safety mechanism that does not allow detonation before the round is fired;
- the ignition cartridge must resemble the ignition cartridge used in the live round as much as possible in terms of appearance and dimensions;
- the maximum firing distance must be 100 m, allowing the system to be used on firing ranges and training grounds;
- the minimum firing distance must be 20 m, ensuring the safety of the mortar team.

In accordance with the first task – determine the elements of the external flight ballistics of mortars on short distances. From the conducted research, it was determined that for distances of 100m the theoretically calculated initial velocity for the round is 32÷33 [m/s].

The second task is to determine the required amount of propellant for the reusable training-practice mortar round intended for short distance firing 100 m.

2. Theoretical determination of the required amount of propellant charge for the reusable training-practice mortar round intended for short distance firing

Due to the fact that firing is conducted on short distances, smaller amount of propellant charge is required. The amount of propellant charge required is fewer than the amount found in the standard issue ignition cartridge. The calculation of the internal ballistics can be performed without the need of strength testing the mortar barrel, i.e. without determining the maximum pressure of the propellant gasses.

The main objective is to determine the initial velocity (v_0) as a function of the propellant mass (ω) in the ignition cartridge for firing at a distance of 100 meters i.e. it is necessary to build the dependency- $v_0 = f(\omega)$.

In order for this dependency to be build, it is necessary to know the data about the mortar type, the initial velocities with which the mortar round is launched and the propellant mass in different ignition cartridges.

To perform the calculations related to the developed model an 82-mm High-explosive mortar O-832Д with ten tail fins is used.

To build the graph, an initial velocity value is needed whit zero propellant charge mass. Obviously, with the abundance of propellant charge, the projectile cannot be fired and accordingly the initial velocity will be zero

The initial velocity values for the selected mortar with different charges are presented in Table 1.

Table 1: Initial velocity values for the selected mortar equipped with different charges.

Propellant charge	**Charge mass– ω[kg]**	**Initial velocity – ν_0 [m/s]**
-	0,000	0
base charge	0,008	70
first	0,0215	132
second	0,035	175
third	0,.485	211

With the data from Table 1 a graph is constructed showing the dependencies of the initial velocity (v_0) as a function of the propellant $v_0 = f(\omega)$, presented in Figure 1.

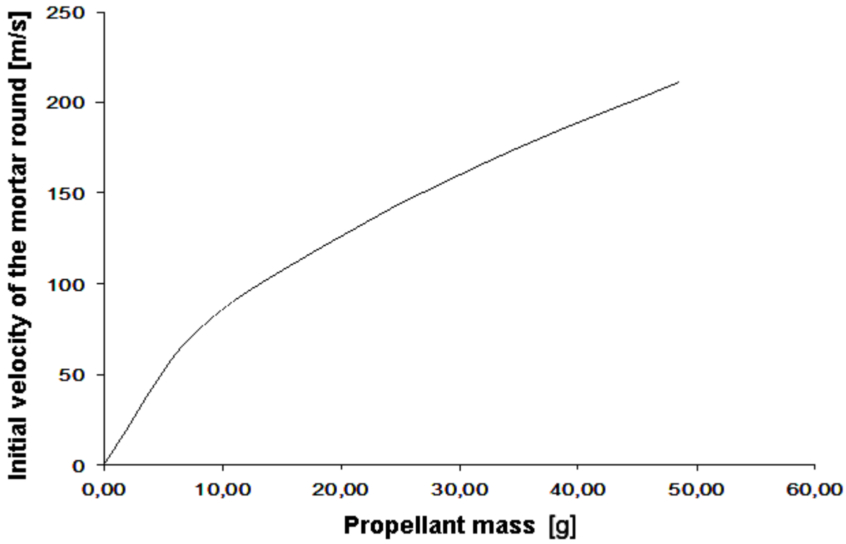

Figure 1: Graph showing the dependence between the initial velocities in a function of the propellant mass.

The Heidernach formula can be used to calculate the estimated mass of the propellant charge:

$$\frac{v_{01}}{v_{02}} = \left(\frac{\omega_1}{\omega_2}\right)^m \qquad (1)$$

where:

v_{01} – initial velocity with the lowest propellant charge selected;

v_{02} – initial velocity for the required propellant charge;

ω_1 – mass of the smallest charge;

ω_2 - mass of the required charge.

The value of the denominator "m" can be determined on the basis of the experimental data via the formula:

$$m = \frac{\lg \frac{v_{01}}{v_{02}}}{\lg \frac{\omega_1}{\omega_2}} \qquad (2)$$

If the values from table 1 for the 82 mm mortar round are used and the highest charge is the third and the lowest one is the base charge, the value for the denominator is calculated: m= 0,61225.

The analysis of formula (2) reveals that:

- it can be use when the mass of the lowest used charge is known i.e. $\omega_1 < \omega_2$;
- the dependence $v_0 = f(\omega)$ from a mathematical point of view and is a power function.

The problem when using this formula is that during short-range firing the mass of the charge sought is less than the mass of the smallest known charge i.e. $\omega_1 > \omega_2$.

This requires another approach in building the dependency $v_0 = f(\omega)$ for the full range of values.

Using the data in Table 1, an approximation is performed with a power function of the type:

$$y = a.x^b \tag{3}$$

The results of the least squares calculations as well as the confidence interval are shown in Figure 2.

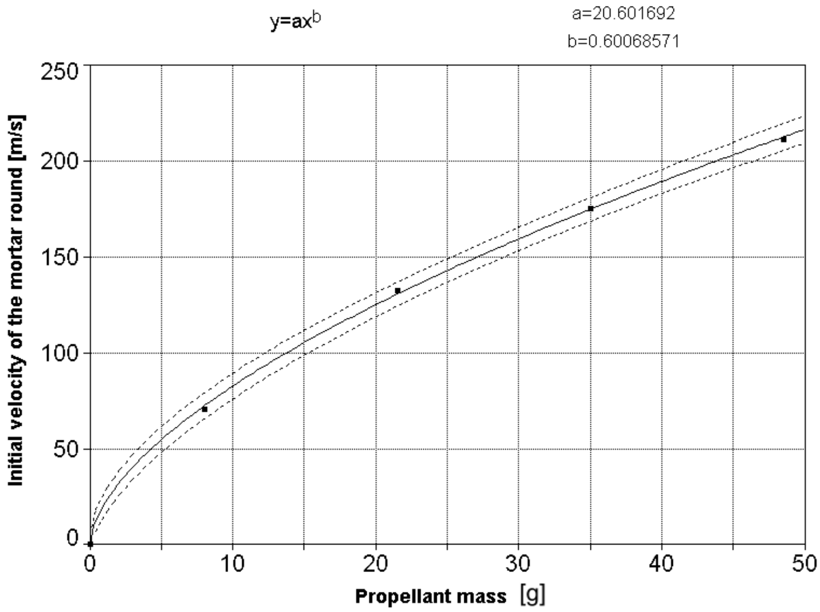

Figure 2: Function graph and confidence interval of function $y = a.x^b$, calculated using the least-square method.

The values for the coefficient and the denominator are calculated:

$a = 20{,}601892$, $b = 0{,}60068571$.

As shown, by taking all values into account and approximating over the whole range of values for the exponent, a value different from the one found in the Heydernach formula is obtained. This indicates that it can use a power function of the above type for approximation, but to obtain a reliable value for its power exponent, it is necessary to take into account the whole range of values.

Accordingly, the required amount of propellant charge can be calculated by the following mathematical formula for power function:

$$v_0 = a.\omega^b \tag{4}$$

where:

ω – propellant charge mass[g];

v_0 – mortar round initial velocity [m/s];

a – coefficient depending on the caliber and mass of the mortar round;

b – coefficient depending on the caliber of the mortar round.

Then the mass of the propellant charge will have the following formula:

$$\omega = \sqrt[b]{\frac{v_0}{a}} = \sqrt[0{,}60068571]{\frac{v_0}{20{,}601892}} \qquad (5)$$

Using the values of the initial velocity of the training practice mortar round 32÷33 m/s for the 82mm mortar, the amount of propellant charge in the ignition charge is calculated via formula (5) is:

$$\omega = \sqrt[b]{\frac{v_0}{a}} = \sqrt[0{,}60068571]{\frac{32}{20{,}601892}} = 2{,}0815$$

$$\omega = \sqrt[b]{\frac{v_0}{a}} = \sqrt[0{,}60068571]{\frac{33}{20{,}601892}} = 2{,}1908$$

Results from the theoretical research indicate that in order for the 82 mm reusable training-practice mortar round to reach 100 m, the base charge needs to be armed with at least 2,2 grams of propellant.

3. Experimental research

In order to check the theoretical research experimental research was conducted. The 82 mm training-practice mortar round was fired at a distance of 100 meters. During the experimental research when taking into account the large amount of blow by between the barrel bore and the mortar round, base charges were made armed with propellant with mass of 2,0, 2,2 and 2,4 g.

The results when firing with the base charge armed with 2,4 grams of propellant were closest to reaching the intended distance of 100 m.

The results gathered from the experimental study from firing the training-practice mortar rounds, armed with 2,4 g smokeless nitroglycerin, ballistic, strip gunpowder, brand NBL-11 (НБЛ – 11) in the ignition charge, fired from an elevation angle of 45^O are presented in table 2.

Table 2: Results from the experimental study gathered from firing the training-practice mortar round armed with 2,4 g smokeless nitroglycerin, ballistic, strip gunpowder, brand NBL-11 (НБЛ – 11) in the ignition charge, fired from an elevation angle of 45^o

№ fired shot	Elevation angle	Expected hit distance	Actual hit distance	Error
	[deg]	[m]	[m]	[%]
1	45^o	100	86	-24%
2	45^o	100	90	-10%
3	45^o	100	97	-3%
4	45^o	100	106	+6%
5	45^o	100	111	+11%
6	45^o	100	115	+15%
7	45^o	100	89	-11%
8	45^o	100	92	-8%
9	45^o	100	103	+3%
10	45^o	100	105	+5%
Average hit and error values			99,4	9,6%

The average firing distance is 99,4 m, with an average error from the experimental study results from firing the training practice mortar-round armed with smokeless nitroglycerin, ballistic, strip gunpowder, brand NBL-11 (НБЛ – 11) in the ignition charge, fired from an elevation angle of 45o is 9,6% .

The big axis of the deviation ellipse is 29 m.

4. Statistics hypothesis checking

The statistics hypothesis can be checked by comparing of the dispersions of the experimental and analytical results. The zero hypothesis is that the dispersion of data, received from the analytical model is commensurable with the dispersion of the experimental data.

Formula (6) can be used to check the statistics hypothesis [5]:

$$\chi_0^2 = \frac{SS}{\sigma_0^2} \qquad (6)$$

where:

$SS = \sum_{i=1}^{n}\left(y_{Ei} - \bar{y}_E\right)^2$ - corrected sum of the squares of the experimental investigation data;

$\sigma_0^2 = \frac{1}{n-1}.\sum_{i=1}^{n}\left(y_i - \bar{y}\right)^2$ - dispersion of the analytical model data;

$\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$ - average analytical model data;

$\bar{y}_E = \frac{1}{n}\sum_{i=1}^{n} y_{Ei}$ - average experimental investigation data;

n - data number.

The zero hypothesis is rejected in cases, when $\chi_0^2 > \chi_{\alpha/2;n-1}^2$ or $\chi_0^2 < \chi_{1-\alpha/2;n-1}^2$ [5]. The values of $\chi_{\alpha/2;n-1}^2$ and $\chi_{1-\alpha/2;n-1}^2$ are tabu1lar [5].

The received results are presented in table 3.

Table 3: Results of zero hypothesis checking

№	α	χ_0^2	$\chi^2_{(0,025;9)}$	$\chi^2_{(0,975;9)}$
1	0,05	12,24168	23,3366	4,40778

5. Conclusions

The results presented in table 3 show that the zero hypothesis can be accepted as true and the analytical model can be used for practical calculation of the powder quantity in the ignition cartridge for the reusable training-practice mortar round for firing on short distances.

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